STRATIGRAPHY OF SOME CENOZOIC DEPOSITS IN THE BIGHORN MOUNTAINS, WYOMING

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ALLEN RALPH LAPPIN

ENTITLED STRATIGRAPHY OF SOME CENOZOIC DEPOSITS IN THE

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN LIBERAL ARTS AND SCIENCES

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FIGURE 1:

INDEX MAP OF WYOMING

(SIMPLIFIED AFTER LOVE, McGREW, AND THOMAS, 1963)

ACKNOWLEDGEMENTS

This study would have been impossible without the thoroughly competent help and guidance given, both in the field and in preparation of the report, by Professor W. H. Johnson of the University of Illinois geology staff.

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ABSTRACT

Isolated patches of buff, well-indurated claystone and coarse terrace gravels are present at several localities in the Bighorn Mountains of Wyoming. The Oligocene age of the claystone is determined by vertebrate fossil remains from outcrops in both the northern and southern parts of the range. In the Burgess Junction region of the northern Bighorns the presence of crystals of amphibole and pyroxene in the claystone indicates that the rock was derived from volcanic ash. Structureless clay pellets in the rock indicate that it underwent at least a moderate amount of fluvial reworking.

Cenozoic terraces in the Burgess Junction region reach an elevation of approximately 8400 feet, some 2000 feet above the Pleistocene Qt_1 terrace level in the Powder River Basin. Both Qt_1 and the best-developed Burgess Junction terraces consist of rounded gravels of Madison Limestone in a sandy matrix and have developed nearly identical caliche zones in their upper part. Therefore, it is concluded that the terraces in the Burgess Junction region are Pleistocene in age. The Burgess Junction terraces are divisible into definitely two and probably three levels with distinctive differences in composition or elevation between levels. The great break in elevation between Qt_1 and the Burgess Junction terraces seems to be structurally controlled, as is preservation of the terraces and underlying claystone.

Outcrops at Canyon Park in the southern Bighorns consist of indurated claystone, coarse conglomerates, tuffaceous sands, and unconsolidated sands and gravels, and are Oligocene and Miocene in age. At the base of "Darton's Bluff" is a claystone appearing to be correlative with that at Burgess Junction. All Oligocene claystone in the Bighorns is probably correlative with the White River Formation of the Great Plains and Wiggins Formation of the Absaroka Mountains.

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I. INTRODUCTION

The Bighorn Mountains of north-central Wyoming (Fig. 1, frontispiece) are located between the Powder River Basin to the east and the Bighorn Basin to the west. The most rugged topography in the range is developed on its large Precambrian core. However, Paleozoic rocks dipping into the adjacent basins form many prominent ridges and flatirons between the Precambrian and the low hogbacks generally developed on the Mesozoic units. The Mesozoic hogbacks, which are well-developed along the west margin of the Powder River Basin, are generally truncated by Cenozoic armored pediments. Cenozoic units are limited largely to the floor of the Bighorn and Powder River Basins. However, isolated patches of Cenozoic claystone and terrace gravels have been reported by several authors along the high flanks of the Bighorns.

The main purposes of this study are to determine the possible correlation and origin of the Cenozoic deposits in the Bighorns, to determine the relationships between the Cenozoic terraces on the high flanks of the range and terraces in the Powder River Basin, and to map the terraces and Cenozoic claystone in the vicinity of Burgess Junction, located 23 miles west of Dayton, Wyoming, at the intersection of U. S. Highways 14 and 14a. In order to determine the origin of the claystone thin sections were made of those samples showing significant sedimentary structures, and X-Ray powder diffraction tests were run where possible.

GENERAL STRUCTURE

The anticlinal shape of the Bighorns is probably related to block faulting of the Precambrian "basement" rocks, as first suggested by W. T. Thom (1933). This faulting is expressed in the overlying Paleozoic units by the development of monoclines, between which there is often little folding. In the short limbs of the monoclines, however, the beds are sometimes nearly vertical. Because there are a larger number of folds on the west side of the range, and because the average dip of the Paleozoic beds between monoclines is greater on the east side, the range appears asymmetric, with its steep front to the east.

The Tongue River Fault to the north and Tensleep Fault to the south effectively divide the Bighorn Mountains into three separate blocks, as shown in Figure 2. The core of the central block has a great deal of Precambrian rock exposed, and contains the highest summit in the range, Cloud Peak (13,175 feet). Much of the central block was glaciated during the Pleistocene and the extent of these glaciers was reported by Darton (1906). The northern and southern segments of the range are much lower than the central block. Probably for this reason they have retained their Paleozoic cover and are largely unglaciated.

GENERAL STRATIGRAPHY

The Paleozoic rocks of the Bighorns have been described by Darton (1906) and by Koucky and Cygan (1963). Table I gives the names and thicknesses of the Paleozoic units as measured by Koucky and Cygan along U. S. 14 on the eastern flank of the range. Of the units shown the Bighorn Dolomite, Madison Limestone, and Tensleep Sandstone are prominent ridge formers.

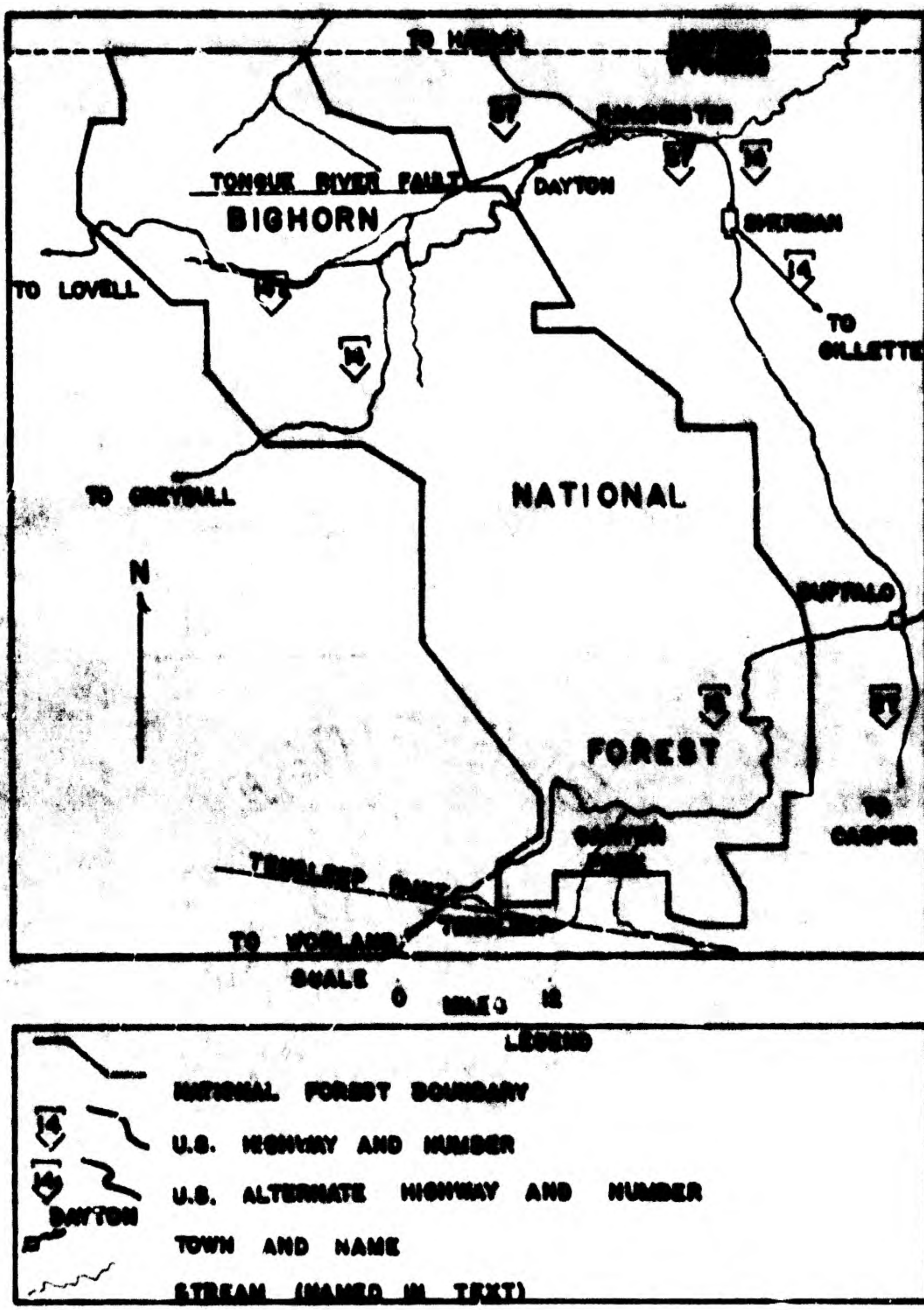

FIGURE 2: GENERALIZED INDEX MAP OF BIGHORN MOUNTAINS

TABLE I

PALEOZOIC UNITS ALONG U. S. 14, EAST FLANK OF THE BIG HORN MOUNTAINS, WYOMING (AFTER KOUCKY AND CYGAN, 1963)

	Unit and Period	Thickness, In Feet
11.	"Permian unit," now termed as Goose Egg Formation, Permian	56
10.	Tensleep Sandstone, Pennsylvanian	108
9.	Amsden Formation, Pennsylvanian	247
8.	Madison Formation (Limestone), Mississippian	870
7.	"Purple unit" and "Yellow unit," now Darby Formation, Devonian	86
6.	Bighorn Dolomite, Ordovician	368
5.	Lander Sandstone, Ordovician	6 to 10
4.	Harding "equivalent" Sandstone, Ordovician	33
3.	Gallatin Limestone, Cambrian and Ordovician	168
2.	Gros Ventre Shale, Cambrian	615
1.	Flathead "Sandstone" (Formation), Cambrian	350

The Powder River Basin is filled largely with the Paleocene Fort Union and Eocene Wasatch Formations. However, Oligocene rocks tentatively considered as part of the White River Formation form the upper part of the Pumpkin Buttes, which are located 25 miles east of Kaycee, Wyoming. As described by Love (1952) the Oligocene rocks at the buttes consist of coarse, cross-bedded, conglomeratic sandstone caprock overlain by thin remnants of claystone.

Along the west edge of the Powder River Basin four distinct terrace levels are developed. The highest of these, identified as Qt_1 in this report, is an extensive armored pediment. It has been mapped in part by Bullard (1967), and consists of Precambrian-free gravels up to 40 feet thick. Three lower terraces, referred to as Qt_2 through Qt_4, are often well-developed in stream valleys along the front of the Bighorns, and are easily distinguished from Qt_1 by their smaller areal extent, lower elevations relative to present drainage, and extensive content of Precambrian lithologies. The Cenozoic terraces in the Burgess Junction region appear quite similar to Qt_1 in lithology. However, since the terraces at the edge of the basin seem to form a level some 2000 feet lower than is indicated by terraces near the crest of the Bighorns, most authors have assigned the higher terraces a Tertiary age.

PREVIOUS WORKERS

The Bighorns were first mapped by N. H. Darton in 1906, and his work remains the only comprehensive study of the area. He mapped several areas of possible Oligocene rocks along the high flanks of the range. Darton suggested the Oligocene age for the rocks because of the strong lithologic similarity with rocks of definite Oligocene age in the Badlands of South Dakota. F. W. Osterwald (1959) studied the structure and petrology of part of the northern Bighorns, and included several patches of Oligocene outcrops in his map. It was Osterwald who first found identifiable vertebrate fossil remains in the claystone, fixing its age as Oligocene. In their mapping neither Darton nor Osterwald distinguished the claystone from overlying terrace gravels.

J. H. Mackin (1937) referred to coarse Tertiary stream gravels high on the west flank of the Bighorn range, but did not map them. Love (1952) studied the Oligocene rocks found at the Pumpkin Buttes, but also referred to rocks of the same age found at unspecified localities "on the crest of the Bighorns." In later works (1960, 1963) he referred to maximum thicknesses of Oligocene and Miocene rocks in the range, but still did not give specific localities. Writers such as Richards (1955), Mapel (1959), and Hose (1955) have discussed the possible Tertiary age of Qt_1 in the Powder River Basin and have described Tertiary valley fills along the flanks of the Bighorns.

Van Houten (1952) described a section measured along "Darton's Bluff," near Canyon Park in the southern Bighorns, but did not specifically study its correlation with surrounding outcrops. Recently McKenna (1968) has reported Arikareean (Miocene) mammal remains from the upper parts of the bluff.

II. BURGESS JUNCTION AREA

DRAINAGE AND GENERAL STRATIGRAPHY

The area around Burgess Junction (Plate 1) is drained largely by the Tongue River and its tributaries. The South Tongue River drains the glaciated areas south of the junction and joins North Tongue River below Skull Ridge. Tongue River then drains eastward and, after passing through Box Canyon, enters the Powder River Basin, where it is joined by Sheep Creek. Much of the area mapped is drained by either North Tongue River or by its tributaries, Fool Creek, Hay Creek, and Camp Creek. Streams north of Fool Creek drain eastward into Dry Fork Creek, which in turn flows northward into the Little Bighorn River.

The Burgess Junction region contains outcrops of Precambrian, Paleozoic and Cenozoic rocks. Precambrian gneissic granite predominates south of the junction proper, and is also found in places along the valley of the North Tongue (Plate 1). Broad, open grasslands and valley slopes are developed on the shaly Flathead and Gros Ventre formations, and are used extensively for cattle grazing. The Ordovician Bighorn Dolomite forms Twin Buttes, Garden of the Gods, and Freeze Out Point, all three of which are major ridges in the area. The Madison Limestone, another dominant ridge former, supports the highest part of the divide between Hay Creek and Fool Creek, forms the high ridge east of Schuler Park, and is present just north of the Camp Creek divide and at Sawmill Flats. The Tensleep Sandstone crops out only beneath the terrace developed where the Freeze Out Point road crosses Fool Creek (Plate 1).

North of the valley of the North Tongue, the Paleozoic units have an average northeasterly dip of about 10 degrees. However, two well-developed monoclines are present in the mapping area and form Dry Fork and Freeze Out Point ridges. Structural relief along Dry Fork Ridge is such that the Pennsylvanian Amsden Formation forms the floor of the valley to the west, while the Bighorn Dolomite is present at the top of the ridge.

WHITE RIVER CLAYSTONE

Occurence

Pale buff, massive claystone of Oligocene age is exposed in the valleys of the North Tongue River, Hay Creek, and Sheep Creek, in Schuler Park, and at the Camp Creek divide. It is also present, to a limited extent, beneath the Fool Creek and Sawmill Flats terraces.

Problematical, highly colored white and pink clays were found in several localities, generally associated with outcrops of the Madison Limestone. These clays are plastic, poorly lithified, and highly calcareous, and often contain angular limestone fragments. The best outcrops of these clays occur in fresh roadcuts along U. S. 14a west of Bear Lodge, and at two places along the new Fool Creek Road, just west of the Hay Creek terrace (NE¼, NE¼, Sec. 27, T. 56 N., R. 89 W.), and in Fool Creek Basin. In Plate 1, outcrops containing either lithified or unlithified clays are indicated by means of a filled triangle (▲).

The well-lithified claystones are found as valleys fills, and reach an elevation of at least 8350 feet in the mapping area. This indicates that, where preserved, the claystone should be found in other stream valleys at comparable altitude. Unfortunately, the claystone is very non-resistant, and is therefore likely to be found only where it has been protected by an overlying terrace cap.

In such areas as along Hay Creek and at the Camp Creek divide slumping and associated spring development can be used to map the lateral limit of the claystone, since the Paleozoic units surrounding the clays are ridge-formers. Where the shaly Flathead or Gros Ventre formations are associated with the White River outcrop slumping and the development of springs is no longer limited to the claystone. However, the limit of the claystone can still be approximately placed, since colluvium containing shale fragments from the Gros Ventre or Flathead is characteristically a dark green or greenish brown color, while that containing fragments of White River claystone is light buff in hue.

Description

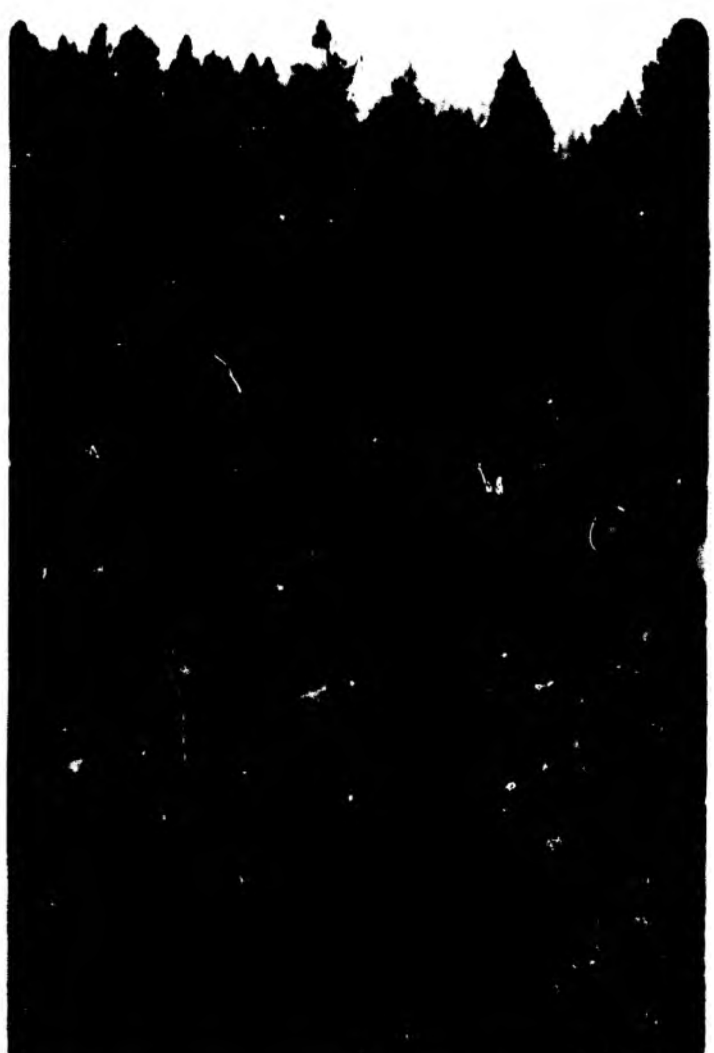

Figure 3. Small Spring and Outcrop of White River Claystone, NE¼, SW¼, Sec. 24, T. 56 N., R. 89 W., Bighorn Mountains, Wyoming.

The two best exposures of claystone are found along the north side of Hay Creek (NE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 24, T. 56 N., R. 89 W.), and at the Camp Creek divide, located between the West Fork of Sheep Creek and the headwaters of Camp Creek (Plate 1). Along Hay Creek the exposures occur in areas of slumping, and at two associated small springs, one of which is shown in Figure 3. At the Camp Creek divide slumping and springs are also evident, but the claystone is best-exposed in gulleys along the Freese Out Road. The claystone at these two localities is white to very pale buff in color (10YR $\frac{8}{2}$ - $\frac{8}{4}$, dry), massive, and well indurated. At the Camp Creek divide it is slightly arenaceous, and non-calcareous.

However, claystone from the spring-level outcrops along Hay Creek contains clay pellets up to 3/8" in diameter, is slightly calcareous, and is penetrated by burrows up to 1/4" across. The pellets are slightly oblong, and in hand specimen appear to be structureless, smooth and unweathered. They do not appear to have any preferred orientation in the matrix. The calcareous material in these rocks appears to be largely crystalline calcite lining the often branch-like burrows, since effervescence of the matrix is minimal. The burrows, up to 1" long, appear to have no preferred orientation, and in addition to being lined with calcite, are either surrounded by or lined with an outer layer of granular pyrolusite. Pyrolusite dendrites are present on joint surfaces.

In thin section, the matrix of the claystone appears to be slightly irregular. Areas of tighter packing are interspersed with regions in which individual clay particles are visible, possibly due to partial flocculation of the clays. Although most of the rock texture is too fine-grained to allow optical identification of the crystals some larger, identifiable grains are present in both matrix and pellets. Quartz and alkali feldspar grains up to 200μ in size make up most of the identifiable fraction, but two relatively unstable minerals are also present.

Although rare, the most common of these unstable mafic minerals present is brown pyroxene. This is found as moderately altered, subhedral, equant grains less than 100μ in size. The least common of the coarser grains are acicular prisms of blue green amphibole up to 100μ in length. These needles appear to be unaltered, and have an extinction angle of some 20 degrees.

In thin section, the pellets appear to lack any interior structure, except for the orientation of clay particles near the rim parallel to the pellet-matrix contact. Although more tightly packed, the material in the pellets appears to be identical to that forming the bulk of the rock. However, apparently due to weathering, this material is slightly darker, especially near the outer rim of each pellet. Under magnification the calcite-matrix contact in the burrows or tubes is seen to be sharp and fairly regular. The granular pyrolusite mentioned above extends a variable distance from the edge of each burrow to a gradational contact with the unaltered matrix.

X-Ray powder diffraction patterns of claystone from the region near Burgess Junction suggest that the rock is of two main types. The well-lithified rock, such as found along Hay Creek and at Camp Creek divide, shows strong montmorillonite, quartz, and feldspar peaks. In samples from Hay Creek calcite is also evident in the diffraction pattern, and Plusquellec (1966) suggests that there may also be a little glass. The small amounts of amphibole and pyroxene noticed in thin sections of these rocks are apparently not enough to be evident in the diffraction record.

A second type of rock, made up of the highly plastic clays along U. S. 14a and the new Fool Creek Road, consists largely of powdered calcite, which predominates over quartz, feldspar, and montmorillonite. The extremely high calcite content of these clays suggests that they are probably not related to the well-lithified Oligocene claystones found in nearby areas. Their association with limestone outcrops and lack of lithification indicates that they may be the result of breakdown of the associated limestones and quite possibly are Pleistocene in age.

Origin, Age, Correlation

The presence of unaltered amphibole and moderately altered pyroxene in White River claystone from the Burgess Junction region indicates that the rock was formed under conditions allowing limited amounts of chemical weathering and stream transport, since these minerals would be rapidly eliminated under normal conditions. Also, the high montmorillonite content of the claystone is characteristic of altered volcanic ash deposits. It thus seems likely that the small amphibole and pyroxene crystals were deposited from ash clouds crossing the Bighorn range, as was much of the material making up the claystones in which they are found, and that the rock represents altered ash fall deposits, as suggested by Love, 1960.

At least slight fluvial reworking of the claystone before lithification is implied by the clay pellets found in outcrops along Hay Creek, since a biologic origin for the pellets is ruled out by their structureless nature and by the presence of angular quartz and feldspar grains. Carozzi (1960) discusses similar pellets in underclays and kaolinite deposits, and suggests that they are a result of intraformational weathering of clay flakes. After dessication and cracking on the stream banks, the flakes were rounded, reworked, and finally redeposited, after a moderate amount of transport. It would also seem quite likely that quartz and feldspar grains could serve as the nuclei for many pellets. However, there was no concentration of quartz and feldspar in the centers of the pellets studied, nor was there any extra compaction of the matrix around the coarse grains.

The Oligocene age of the claystones in the Burgess Junction area is relatively well established. Osterwald (1959) described a middle toe bone of

Mesohippus, the Oligocene horse, from an outcrop at the Camp Creek divide. The Early Tertiary age of the clays is also supported by the partial remains of Hoplophoneus, an Early Oligocene to Early Miocene sabre-tooth cat, found at the same site by members of the University of Illinois geology staff. Although fossils have been found at only the one locality, the very strong lithologic similarities and mode of occurence of the well-lithified claystones in the Burgess Junction region makes it strongly probable that they are all of nearly identical age.

Love (1939), proposed that a unit composed of interbedded volcanic conglomerates and ash in the Absaroka Mountains be designated as the Wiggins Formation. He assigned the unit an Oligocene age, based on partial remains of Titanothere from the fine-grained ash beds. If the Oligocene age of the claystones in the Bighorn Mountains is correct it seems most probable that they are time-equivalents of the Wiggins and White River Formations and were, as suggested by Love (1960) derived from ash falls from the Absaroka Volcanic Field.

Oligocene claystones from the Bighorn Mountains were first assigned to the White River Formation by Osterwald (1959). In spite of the considerable differences in lithology between these rocks and those in the type area of the White River Formation the term White River has been used here since, given the limited amount of outcrop of the claystone, there seems to be no need to propose a new, formal lithostratigraphic unit for Oligocene outcrops in the Bighorns.

CENOZOIC TERRACES AND TERRACE GRAVELS

Occurence

Cenozoic terrace gravels in the Burgess Junction area are generally found closely associated with the older White River claystone. Thus, as shown in Plate 1, the gravels, indicated by a horisontal line pattern, are limited largely to the valleys of the North Tongue River and its tributaries, but are also found along Sheep Creek and at Sawmill Flats. The gravels are best exposed along Hay Creek (S½, Sec. 23, T. 56 N., R. 89 W.) and in Sec. 34, T. 56 N., R. 89 W., northwest of the PK Cow Camp. At these two localities they form a high relatively flat terrace cap, as shown in Fig. 4.

Figure 4. Upper Surface of Hay Creek Terrace, S½, Sec. 23, T. 56 N., R. 89 W., Bighorn Mountains, Wyoming.

Description

The Hay Creek and PK terrace gravels are up to fifty feet thick and consist almost entirely of subrounded to rounded pebbles and cobbles of Madison Limestone. The cobbles, averaging 6 to 7 inches in diameter, range in size from ½" to a foot or more. The matrix of these gravels is made up of sand and calcareous cement, although the amount of cement and resulting lithification appear to decrease upward.

In the lower part of the Hay Creek and Camp Creek terraces, exposed largely on the scarp faces behind recent slumps, is a discontinuous, thin zone of highly angular, well-cemented conglomerate containing fragments of Gros Ventre and Gallatin limestone, as well as pebbles from the Madison. The sub-angular to sub-rounded pebbles in this unit are generally less than 2 inches in size, and are tightly cemented together by crystalline calcite. However, several crystal-lined vugs are still evident. Thin section study of this unit indicates that it is free of clay and sand particles.

The terrace gravel-claystone contact is sharp and apparently erosional. On the north side of Hay Creek the contact occurs on a surface having some 6 inches of relief (see Fig. 5). Claystone immediately below the contact is slightly arenaceous, non-calcareous, and friable, perhaps due to leaching. However, its color is the same as that of claystone at the stream level below and it does not appear to have been otherwise weathered.

Although the highly angular conglomerate described above is missing at this locality, the gravels directly above the terrace-claystone contact are more fine-grained than those in the main part of the terrace. In the first 10 inches above the contact pebbles 1/4 - 3/8" in size are irregularly interbedded with cobbles up to 4" in diameter. Above that level the diameter of cobbles in the gravels again averages some six to seven inches.

Figure 5. Contact between White River Claystone and Cenozoic Terrace Gravel, SE¼, SW¼, NW¼, Sec. 24, T. 56 N., R. 89 W., Bighorn Mountains, Wyoming.

Figure 6. Caliche Zone in Top of Hay Creek Terrace, SE¼, SW¼, Sec. 23, T. 56 N., R. 89 W., Bighorn Mountains, Wyoming.

A small pit near the west end of the Hay Creek terrace revealed a 10-foot section of terrace gravels, three feet of which are welded into a plugged caliche, sh[illegible] in Fig. 6. Bullard (1967) described a very similar caliche at the top of Qt_1 in the Powder River Basin. Table II contains descriptions of the caliche developed at Hay Creek and on Qt_1. The similar development of caliche in the two areas and the similar nature of the underlying gravels and overlying soils seem to suggest that the two terrace may well be of the same age.

Division Into Levels

On grounds of composition and elevation the Cenozoic terraces in the Burgess Junction region can be divided into at least two and probably three distinct levels. The Hay Creek and PK terraces, with probable inclusion of the terrace at Sawmill Flats, form the highest and best-developed level. These terraces completely lack Precambrian lithologies and, with the exception of the angular unit at the base of the Hay Creek terrace, consist entirely of rounded gravels of Madison Limestone.

All three terra[illegible]s show varying amounts of draping around the bedrock supporting them. This effect is most evident in the Sawmill Flats terrace, which is saddle shaped, due to the presence of higher outcrops of bedrock on the east and west. Also, as shown in Fig. 4, the Hay Creek terrace shows considerable draping around an outcrop of Madison Limestone near its west end. The PK terrace shows the least draping, although it is broken into two parts by an outcrop of Cambrian limestones and shales.

In spite of the draping the terraces forming the highest level appear to have a general northeasterly slope. While the elevation of these terraces decreases only from 8400 feet at the west end of the PK terrace to 7800 feet at Sawmill Flats the gradient is apparently steeper between the PK and Hay

TABLE II

STRATIGRAPHIC SECTIONS OF Qt_1 (BULLARD, 1967) AND HAY CREEK TERRACE, BIGHORN MOUNTAINS AND POWDER RIVER BASIN, WYOMING

	Qt_1, Bullard, 1967	Thickness, In Feet
6.	Gray brown silty loam	.1
5.	Transition zone of compact dark brown clay loam	.25
4.	Dense, brown prismatic clay loam	.6
3.	Grey brown sandy loam with white pebbles	.8
2.	Well cemented caliche	2.5
1.	Gravel armour deposit of sub-angular to sub-rounded limestone or dolomite cobbles in a sandy matrix; elongated cobbles imbricated towards mountain front	37
	Hay Creek Terrace, This Report	
5.	Dark, organic-rich silty loam with scattered pebbles	.3
4.	Dark brown to light grey brown prismatic loam; very pebbly	.7
3.	Gradational contact	.2
2.	Well-cemented caliche zone; brilliant white when dry; top 18" quite dense; cobbles same size as in underlying unit	3
1.	Terrace gravels, well-rounded cobbles of Madison Limestone in an arenaceous and calcareous matrix	6

Creek terraces. The best-determined maximum gradient here appears to be 110 feet per mile.

The Sheep Creek and Camp Creek terraces lie at approximately the same level as the PK - Hay Creek - Sawmill Flats group, but can probably be placed in a separa' level because of their content of Precambrian pebbles. These are relatively minor at Camp Creek, but predominate in the Sheep Creek outcrops, which consist almost entirely of coarse quartz sands, with some altered feldspar and rock fragments. The great amount of Precambrian present in the Sheep Creek terraces strongly indicates that they were formed by streams having a vastly different source area than were the Precambrian-free terraces at approximately the same level.

A second definite terrace level is developed on two low terraces in the valley of the North Tongue River and possibly at the Fool Creek divide. The terraces in the valley of the North Tongue are at an elevation of 8080 feet, directly below the PK terrace, while the Fool Creek divide, northeast of the Hay Creek terrace, is at an elevation of some 7600 feet (Plate 1). Both sets of terraces completely lack Precambrian lithologies, although the ones along North Tongue do contain cobbles of Bighorn Dolomite.

The northeasterly slope of the Precambrian-free PK and Hay Creek terraces and the lack of Precambrian in the terraces at an elevation of some 8080 feet in the valley of the North Tongue indicate that these levels were formed by streams draining from the southwest. Exposures of Precambrian are limited in this direction at present, and were presumably even more restricted in the past. In fact it seems quite probable that the present North Tongue is responsible for the low terraces in its present valley.

The terraces at Camp Creek and along Sheep Creek were most probably formed by streams flowing from the south, since it is in this direction that Precambrian rocks outcrop most extensively. At present the South Tongue River drains these Precambrian-rich areas, but enters the Tongue River south of the Hay Creek - Sheep Creek region. However, the highly angular relationships between South Tongue and Tongue rivers shown in Plate 1 indicate that South Tongue may well have been recently captured by Tongue River, the capture post dating the Camp Creek and Sheep Creek terraces. Also, as shown in Plate 1, South Tongue River south of Arrowhead Lodge, the anomalously large swamps along Nickle Creek, and outcrops of Precambrian-rich gravels and interbedded claystone in the region of Arrowhead Lodge form a well-defined trend towards Dry Fork valley, suggesting that South Tongue or streams ancestral to it formerly flowed northward beyond its present junction with North Tongue River. While the Camp Creek and Sheep Creek terraces do not lie directly along this trend, it seems quite possible that they were formed by streams draining to the north or northwest, along Dry Fork valley.

Relation to Terraces in the Powder River Basin

In spite of the great elevation of the Hay Creek and FK terraces they are quite possibly correlative with Qt_1 in the Powder River Basin. This belief is based largely on the strong similarities in appearance of the two levels and, more importantly, on their strong lithologic similarities. Both levels are made up of Precambrian-free gravels more than 25 feet thick, set in a sandy or sandy and calcareous matrix. Also, as shown in Table II, the two levels show development of quite similar caliche zones.

Bullard (1967), from work along the margins of the Powder River Basin, has suggested an Early Pleistocene age for Qt_1. In a few silty pods within the gravel deposits he found a gastropod fauna containing Columnella edentula, Vallonia excentrica, and Fossaria sp. . These species indicate, according to Bullard, that Qt_1 can be no older than Aftonian. If so the terraces in the Burgess Junction region are also probably Pleistocene in age.

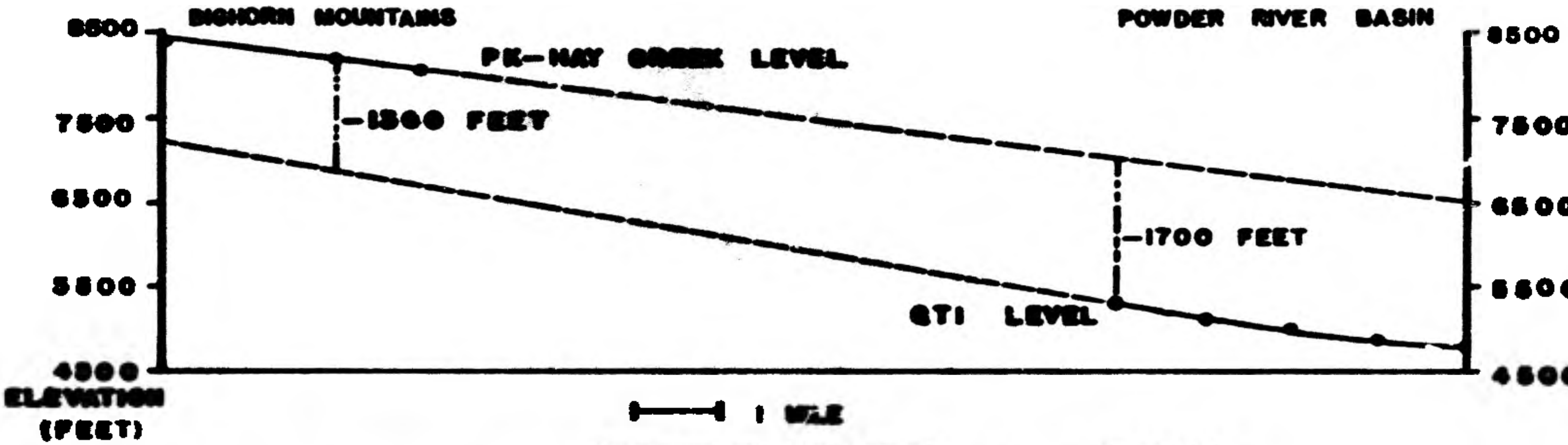

FIGURE 7a: RELATIONSHIP BETWEEN PK—HAY CREEK AND QT1 TERRACE LEVELS, BIGHORN MOUNTAINS AND POWDER RIVER BASIN, WYOMING

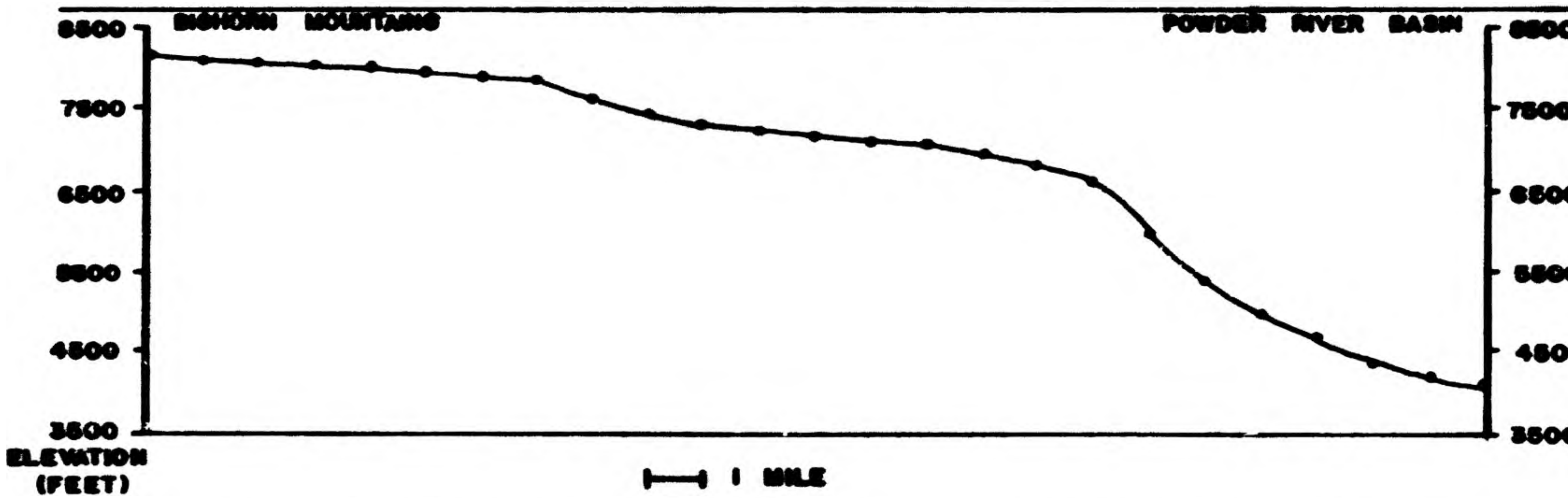

FIGURE 7b: STREAM PROFILE OF NORTH TONGUE AND TONGUE RIVERS, BIGHORN MOUNTAINS AND POWDER RIVER BASIN, WYOMING

The obvious difficulty with this interpretation is that the PK - Hay Creek terrace gradient, projected eleven miles to the edge of the Powder River Basin, falls 1700 feet above Qt_1 at that point, as shown in Fig. 7a. Also, although the Hay Creek and PK terraces are closer to the presumed source area of the gravels they have a gradient of only 110 feet per mile, while the measured slope of Qt_1 close to the mountain front is greater than 150 feet per mile. As shown in Figure 7a, the Qt_1 level, projected back to the Hay Creek terrace, is some 1300 feet too low.

Fortunately the large disparity between the elevation of the two terrace groups is matched by a large break in gradient and elevation along the profile of North Tongue River and Tongue River, as shown in Fig. 7b. Sections of the river above and below Box Canyon, separated by some 2500 feet in elevation, have gradients less than 200 feet per mile. Within the canyon the stream drops as much as 600 feet per mile and is obviously rapidly downcutting.

The present downcutting into the Precambrian is made necessary by the presence of the Horse Creek Ridge-Skull Ridge monocline, dating probably from the uplift of the range in Eocene time, but at any rate from pre-Pleistocene time. Given the present break in stream elevation and gradient across this structure it seems likely that the present Tongue River drainage was not developed in Early Pleistocene time, and that capture of North Tongue and South Tongue has taken place only recently. Thus, while the northward draining streams in the Burgess Junction region were forming terraces relative to a structurally effected local base level, streams, such as the ancestral Tongue River, draining radially at the flanks of the Powder River Basin, were forming contemporaneous terraces at a much lower level.

Further evidence that the monoclines served to prevent integration of the Early Pleistocene drainage, and are still doing so today, is provided by Dry Fork Creek, which drains to the northwest and is a tributary of the Little

Bighorn River. Thus, it does not cross the monoclines, but flows parallel to them. In spite of the long path by which Dry Fork must reach the Powder River Basin its valley and valleys tributary to it, such as Garland Gulch and Lake Creek valley, are quite steep-sided and narrow, and seem to lack deposits of both White River claystone and alluvial terrace. The fact that the valleys of North Tongue River and its tributaries are fairly broad and have relatively gentle slopes must then be due to the structrual blocking of the present Tongue River drainage by the Horse Creek Ridge - Skull Ridge monocline.

III. CANYON PARK

Canyon Park is located some 30 miles west of Buffalo, Wyoming via U. S. 16 and some 3 miles south of U. S. 16 on the Gold Mine Road (Fig. 2). On the east side of the valley, forming the drainage divide between Canyon Creek and the North Fork of the Powder River, stands "Darton's Bluff" (Secs. 18 and 19, T. 48 N., R. 85 W.), photographed in Darton's 1906 professional paper.

Since Darton's time several authors have discussed the probable Oligocene and Miocene age of the rocks along the bluff. Van Houten (1952) divided the exposures into three units, as did Darton. Van Houten's basal unit is some 30± feet thick and consists of "calcareous, tuffaceous buff arkosic mudstone with lenses. . . . [of] rotten schist pebbles." On the basis of lithologic similarities with the tuffaceous upper part of the White River Formation of the Great Plains he suggested that this basal unit might be Oligocene in age.

Van Houten's middle unit consisted of 70± feet of tuffaceous and shard-rich, massive, buff sandstone, which he suggested, on lithologic grounds, might well be Miocene in age. His top unit, 100 - 160 ± feet thick, consisted of unconsolidated conglomerates and gravels, with some lenticular bodies of sand quite similar to that in his middle unit.

McKenna (1968) has described an Arikareean mammal fauna from the middle, massive sandstone member of VanHouten and Darton, including the genera Desmatolagus, Entoptychus, Gregorymys, Promylagaulus, cf. Oreodontoides, and Miotylopus. Unfortunately, he did not give any fossil control for the over-lying or underlying units.

Members of the University of Illinois geology staff have found vertebrate fossil remains in nearby localities in the southern Bighorns. From a fairly large outcrop of claystone in the NE¼, Sec. 14, T. 46 N., R. 85 W., a Mesohippus tooth, probably from a mid to late Chadron species, has been identified. Also, from claystone in Sec. 18, T. 48 N., R. 85 W., less than a mile north of the main part of Darton's Bluff, a Mesohippus foot bone (subterminal phalanx) and unidentified artiodactyl ankle bone (astragalus) have been removed. As a part of this study a detailed stratigraphic section of Darton's Bluff given in Table III was measured, and a short search for fossil remains was made in the area.

Of greatest interest is the lowest claystone, unit 1, which is not described by either Darton or Van Houten. Although slightly arenaceous it otherwise appears quite similar to the lithified claystone found in the Burgess Junction region and at several localities near Canyon Park. On the basis of this lithologic similarity and the presence of bone scraps similar in general character to those from Camp Creek and other local outcrops this lowest unit is probably Oligocene in age. At any rate, due to the presence of Arikareean fossils in unit 9, Van Houten's middle unit, the lowest claystone is at least Miocene.

The unconsolidated sands and boulder gravels above unit 9 form an almost vertical face as shown in Fig. 8. At the locality shown in the photograph the beds seemed to be dipping to the southeast at 5 to 8 degrees. Unfortunately, areas suitable for direct measurement of the dip were inaccessible without climbing equipment. Mackin (1937) and others feel that the measured dips in many similar Tertiary outcrops on the flanks of mountain ranges surrounding the Great Plains are most probably depositional in origin, rather than being due to tilting of the mountains after deposition. If so, the amount of basin filling in the Powder River Basin required to allow deposition of fine-grained sediments and gravels along the high flanks of the Bighorn range need not have been great.

TABLE III

STRATIGRAPHIC SECTION OF "DARTON'S BLUFF,"
SEC. 19, T. 48 N., R. 85 W.,
BIGHORN MOUNTAINS, WYOMING

Station A: In Sec. 19, T. 48 N., R. 85 W., on steep scarp face exposed by recent slumping.

Unit	Description	Thickness, In Feet
15.	Sand: pale brown (10 YR 6/3, dry); grains sub-rounded, 1/8 - 1/4" in size, largely quartz, but with 5 - 10% dark mineral; four 2"-thick zones rich in dark material in top 7' of unit; top zone contains charcoal and occurs at base of shallow, weakly developed soil	10
14.	Sand and boulder gravel: interbedded; sand light yellowish brown (10 YR 6/4, dry); gravels varied in color; sands coarse, poorly bedded, noncalcareous, and in places slightly gr illy, largely quartz with some crystalline Precambrian; boulders are up to 2' in diameter, largely Precambrian metamorphics, rounded to subrounded, partly rotten; top 3' of unit contains clay skins and shows gradual color change to dark yellow brown (10 YR 4/4, dry)	28.5
13.	Sands and gravels: interbedded; sand very dark grayish brown (10 YR 4/2, dry); fine grained to coarse grained, well bedded, non-calcareous; cobbles 2" - 6" in size are sub-rounded; both sands and gravels are poorly, sorted and contain abundant Precambrian metamorphics; top of unit is marked by a 4" seam of plastic, non-calcareous brown clay (10 YR 5/3, dry)	21.7
12.	Silstone and clay: interbedded; siltstone is light brownish gray (10 YR 6/2, moist), white when dry, well-indurated, non-calcareous, in beds up to 6" thick; clay is also light brownish gray (10 YR 6/2, moist), plastic, and non-calcareous	1.5

TABLE III, (CONTINUED)

STRATIGRAPHIC SECTION [illegible] "[illegible]ARTON'S BLUFF,"
SEC. 19, T. 48 N., [illegible]. 85 W.,
BIGHORN MOUNTAINS, [illegible]YOMING

Unit	Description	Thickness, In Feet
11.	Sand and clay: interbedded; sand is light gray to white (10 YR 7-8/2, dry), fine-grained, in beds up to 1' thick, quartz sand grades upward into clay seams; clay is very pale brown (10 YR 8/3, dry), non-calcareous in seams ½" thick; gradational contact beneath clay and sharp contact above	5.0
10.	Siltstone; very dark grayish brown (10 YR 3/2, moist), massive, well-indurated, non-calcareous; contains pyrolusite dendrites and inclusions of light buff silt; forms notch at top of underlying sandstone	1.8
9.	Sandstone: white (10 YR 8/1, dry), massive, fine-grained, tuffaceous, non-calcareous; contains randomly oriented amphibolite fragments up to 2" in size in lower 18' of unit; glass shards abundant	67
8.	Sandstone and conglomerate: interbedded; sandstone is white (10 YR 8/1, dry), faintly cross-bedded, fine-grained, tuffaceous, and non-calcareous; conglomerate lies in cut and fill stream channel, subangular, dark green cobbles of Precambrian amphibolite up to 6" in size; cobbles aligned parallel to bottom of channel; sharp contact at base of each channel, gradational contact upward	12
		147.5
Station B:	In middle of slope, approximately 200 yards north of Station A. Section here begins 26 feet above base at Station A.	
7.	Sandstone: white (10 YR 8/1, dry), massive, fine-grained, tuffaceous, non-calcareous; contains randomly oriented amphibolite fragments up to 1" in size; glass shards abundant; equivalent to unit 9 . .	20

TABLE III, (CONTINUED)

STRATIGRAPHIC SECTION OF "DARTON'S BLUFF,"
SEC. 19, T. 48 N., R. 85 W.,
BIGHORN MOUNTAINS, WYOMING

Unit	Description	Thickness, In Feet
6.	Limestone: poorly bedded, contains fragments of amphibolite, quartz, and granite, up to ¼" in size; also much fine-grained dark material; weathers into large, rounded blocks	5.5
5.	Limestone conglomerate: pebbles and cobbles of quartz, feldspar, and Precambrian amphibolite in a sandy, calcareous matrix, well-stratified; grains from ¼" to 6" in size, with finer pebbles in lower part and coarser cobbles concentrated near top of unit	3
4.	Limestone: white (2.5 Y 8/1, dry); massive, clastic, very fine-grained; has a few small stringers of amphibolite along poorly defined arcuate bedding planes or cut and fill channel beds; contains micro-crystalline, structureless nodular bodies up to 3" in size; these have a very sharp contact with the matrix, and have pyrolusite dendrites on outer surface	5 - 7
3.	Conglomerate: Pre-Cambrian quartz, feldspar, amphibolite and schist cobbles and boulders from ¼" to 2' in diameter; average 5" - 6"; sub-rounded with horizontal preferred orientation of less rounded cobbles; matrix is light buff, indurated, fine-grained limestone: upper contact shows 2' relief	5 - 7
2.	Limestone: white (2.5 Y 8/2, dry), massive, poorly indurated; contains dark angular fragments of reworked limestone up to ¼" in size, unit forms notch at base of overlying conglomerate; base not exposed	1.5
		42.0

TABLE III, (CONTINUED)

STRATIGRAPHIC SECTION OF "DARTON'S BLUFF,"
SEC. 19, T. 48 N., R. 85 W.,
BIGHORN MOUNTAINS, WYOMING

Station C: Ca ½ mile south of Station B, at base of inaccessible face near bottom of bluff. Top of section ca. 20 feet below conglomerate appearing to be quivalent to that at base of Station B.

Unit	Description	Thickness In Feet
1.	Claystone: white (10 YR 8/2, dry), fine-grained, massive, slightly sandy or tuffaceous, non-calcareous; contains a few pebbles of Precambrian, and a 2' thick layer of non-lithified sand near top; contains unidentifiable bone chips; base not exposed due to extensive slumping	19
		19

Figure 8. Unconsolidated sands and gravels, upper part of "Darton's Bluff," Sec. 19, T. 48 N., R. 85 W., Bighorn Mountains, Wyoming.

Figures 9 and 10: Amphibolite-bearing tuffaceous sandstone. "Darton's Bluff," Sec. 19, T. 48 N., R. 85 W., Bighorn Mountains, Wyoming.

Unit 8 and the lower part of unit 9 contain amphibolite fragments up to 6" in size, but consist dominantly of fine-grained tuffaceous sandstone. As shown in Figure 9 and 10, the large cobbles in unit 8 seem to lie dominantly along fairly well-defined cut-and-fill channels, and seem to have been stream deposited, as is also probably the case of the smaller amphibolite fragments in unit 9. An outcrop of dark green amphibolite was found on a low ridge approximately ¼ mile northwest of station B, and seems to have served as the source area for the fragments in units 8 and 9.

Figure 11. Well-cemented conglomerate, lower part of "Darton's Bluff," Sec. 19, T. 48 N., R. 85 W., Bighorn Mountains, Wyoming.

Figure 11 shows the well-cemented conglomerates making up the bottom unit of Van Houten. It is these units which he suggested might be Oligocene in age.

IV. OTHER LOCALITIES

ARROWHEAD LODGE

Two outcrops somewhat similar in makeup to the terraces along Sheep Creek are found in the vicinity of Arrowhead Lodge, three miles east of Burgess Junction via U. S. 14. The deposits at these outcrops consists of unconsolidated sands and clays, and Osterwald (1959) has suggested that they are White River in age. The best locality is on the south wall of an abandoned gravel pit 3/4 mile north of Arrowhead Lodge and 50 yards east of the highway (Plate 1). The second outcrop, also in an abandoned pit, is located 3/8 mile north of the lodge and 100 yards west of the highway. Both outcrops (see Plate 1) are in an area of relatively low relief, and are less than 80 feet above an unnamed tributary to the South Tongue River.

The best outcrop (see Fig. 12) consists of interbedded, lenticular, non-calcareous, unconsolidated sands, and clays, capped by approximately 9 inches of soil. The pink to orange sands consist largely of quartz, but also contain fragments of Precambrian rocks and some altered feldspar. All types of grains often have well-developed clay skins. Below the face shown in Figure 12 the material is made up of coarse sands and gravels, and continues to an unknown depth. Gravels in the pit west of the highway appear similar to the bottom unit in the main pit, but contain a few clays and some Cambrian limestone pebbles.

The clays at both outcrops are pink to brown, sometimes arenaceous, poorly consolidated, and uniformly non-calcareous. Their X-Ray powder diffraction pattern also shows them to be quite rich in feldspar and

Figure 12. Outcrops of Cenozoic sands and gravels, south wall of abandoned gravel pit, 3/4 mile north of Arrowhead Lodge, Bighorn Mountains, Wyoming.

montmorillonite. In spite of the presence of montmorillonite, it is suggested here that the clays and associated gravels are glacial outwash of Pleistocene or Recent age, since they lie directly in line with the proposed former path of the South Tongue River along what is presently Nickle Creek. It seems quite likely that the montmorillonite in the Arrowhead Lodge outcrops is derived from White River claystone originally present upstream, and that the Arrowhead Lodge and Sheep Creek terraces are approximate time equivalents.

RED GRADE ROAD AND COPPER CREEK

Red Grade Road is located approximately five miles south of Burgess Junction via U. S. 14a, and runs eastward through the unsurveyed Woodrock Quadrangle. The Copper Creek outcrop is located on the north side of Red Grade Road ca. 1 3/4 mile east of U. S. 14a, just north of the flats along Copper Creek, and forms a low hill of interbedded sandstone, claystone, and highly angular to subangular conglomerate.

The conglomerate contains pebbles of Precambrian metamorphic and igneous rocks as well as lower Paleozoic limestone, set in a matrix of highly crystalline calcite. Although much richer in Precambrian pebbles, it is strikingly similar to the well-lithified angular conglomerate at the base of the Hay Creek and Camp Creek terraces, and is quite possibly time-equivalent with that poorly exposed unit. Whereas the stratigraphic position and relationships of the highly angular unit are not clear in the Hay Creek and Camp Creek terraces, it is obviously interbedded with lithified claystone in the Copper Creek outcrop.

This claystone is white to very pale buff, well-indurated, and massive, and on grounds of both lithologic similarity and a nearly identical X-Ray diffraction pattern, can probably be assumed to be equivalent to the White River claystone in the Burgess Junction region. If so the Hay Creek and Camp Creek divide terraces, though largely Pleistocene in age, probably do contain a discontinuous Oligocene conglomerate in their basal part.

The Red Grade Road outcrop, along a recently abandoned section of the road one mile east of U. S. 14a, consists largely of ca. 7 feet of well-cemented conglomerate similar to that at the Copper Creek outcrop, capped with sand and silt. The grain size of the conglomerate increases upward from an average of ca. ¼" to approximately 1½". Due to the limited amount of field time available for this study the outcrops were sampled, but no stratigraphic section was measured.

Approximately ½ mile east of the Copper Creek is located a large terrace, composed entirely of quartz pebbles and Precambrian fragments. This terrace is completely unconsolidated and appears to be extremely similar to gravels at Arrowhead Lodge further north. It is therefore assumed to be Pleistocene in age

PUMPKIN BUTTES

The Pumpkin Buttes are located some 25 miles east of Kaycee, Wyoming, on the floor of the Powder River Basin. Love (1952) described the Oligocene and Eocene rocks in the buttes. The prominent Oligocene unit is a well-cemented, coarse, cross-bedded caprock sandstone, shown in Figure 13. The caprock contains pebbles of quartz, Precambrian crystalline rocks, and according to Love (1952), Tertiary amphiboles.

On top of the caprock a six to eight foot thick remnant of interbedded sandy clays and pure, plastic clays is present. The yellowish gray to light olive plastic clays are non-calcareous, and are quite rich in montmorillonite, quartz, and feldspar. The X-Ray peaks are sharper and more clearly defined than those of the well-lithified claystones from Burgess Junction, but are quite similar to those for claystones from Canyon Park, which are apparently largely Miocene in age.

Love, however, described the partial remains of Leptomeryx and Titanothere from the clays above the caprock, fixing its Oligocene age. The presence of Oligocene sediments at an elevation of some 6000 feet in the Powder River Basin, versus 9000 feet in Canyon Park, seems to support the hypothesis that the dip of the deposits on the high flanks of the Bighorns is primary.

Figure 13. Oligocene caprock on South Pumpkin Butte, Powder River Basin, Wyoming.

V. CONCLUSIONS

On the basis of vertebrate fossil remains from Camp Creek divide and at localities near "Darton's Bluff" the Oligocene age of the well-lithified claystone in the Burgess Junction region, at Copper Creek, and at the base of "Darton's Bluff" is fairly well determined. The claystones are therefore time-equivalents of the Wiggins Formation (Love, 1939) and of the White River Formation. The presence of grains of amphibole and pyroxene from claystone along Hay Creek indicates that the rock is volcanically derived. This conclusion is supported by the great amount of montmorillonite found in the claystone. The presence of structureless clay pellets in the claystone implies that the unconsolidated volcanic ash underwent a moderate but limited amount of stream transport.

The similar caliche zones and strong lithologic similarities between the PK - Hay Creek terrace level in the Burgess Junction region and Qt_1 in the Powder River Basin suggests that the two levels are time-equivalents. If the correlation is correct, Bullard's Aftonian gastropod fauna from Qt_1 establishes the Pleistocene age of the Hay Creek - PK terrace level.

Terraces in the Burgess Junction region can be divided into at least two and probably three levels, a top and bottom level lacking Precambrian cobbles, and a probable third level rich in Precambrian. Gravels somewhat similar to those at the Sheep Creek terraces are found at Arrowhead Lodge and Copper Creek. At least those at Sheep Creek and Arrowhead Lodge seem to have been formed by the South Tongue River, which may have flowed north out of Dry Fork valley before being captured by the Tongue River in recent time.

The great break in elevation between the FK - Hay Creek terrace level and Qt_1 is matched by a large break in the elevation and gradient of the North Tongue and Tongue Rivers. This break is concluded to be due to the Horse Creek Ridge - Skull Ridge monocline, which is also concluded to be responsible for the large break in terrace levels formed before the present Tongue River drainage. Study of the "Darton's Bluff" section revealed a previously undescribed basal claystone unit concluded to be equivalent to the claystone at Burgess Junction. Finally, the presence of interbedded claystone and angular conglomerate at Copper Creek indicates that the angular conglomerate in the Hay Creek and Camp Creek terrace may be Oligocene.

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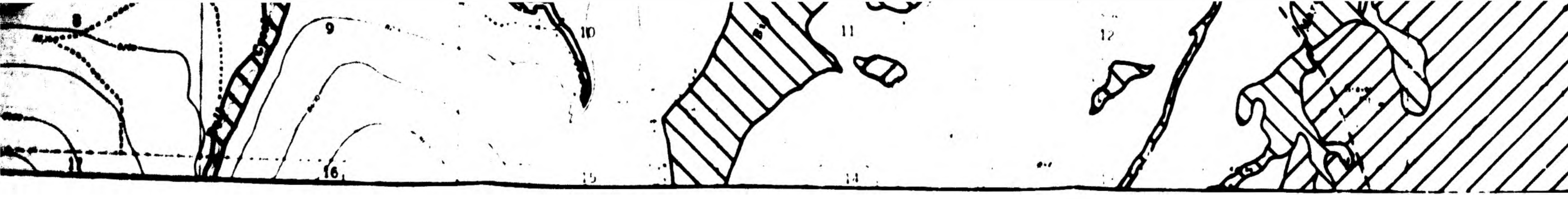

WHITE RIVER CLAYSTONE

FLUVIAL TERRACE

CLAYSTONE OUTCROP

TN

16°

MAGNETIC DECLINATION 1964

SCALE 1:24000

CONTOUR INTERVAL 40 FEET

GEOLOGY BY A.R. LAPPIN

16°
CONTOUR INTERVAL 40 FEET
GEOLOGY BY A.R. LAPPIN
MAGNETIC DECLINATION 1964
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GEOLOGY BY A.R. LAPPIN
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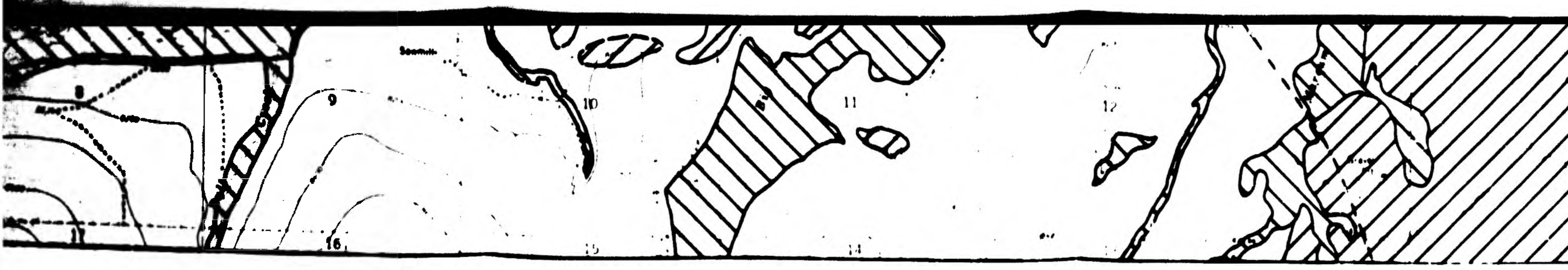
MAGNETIC DECLINATION 1964



ALLUVIUM

WHITE RIVER CLAYSTONE
FLUVIAL TERRACE
CLAYSTONE OUTCROP
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CONTOUR INTERVAL 40 FEET
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